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CURES AND INCREASING PARTICIPATION IN STEM

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ABSTRACT

With increasingly voluble calls from academic and government stakeholders to improve educational and professional outcomes for undergraduates, STEM faculty are continuously inventing new ways to solve old problems such as student attrition and declining graduate rates. Specifically, there have been many appeals to increase the number of undergraduate research experiences for students. Course-based undergraduate research experiences (CURES) have been suggested as a vehicle to move the needle in terms of producing sustainable improvements in higher education. CURES provide opportunities for STEM undergraduates enrolled in a particular course to engage in faculty-mentored, hypothesis-driven research activities. In apprenticeship-style research experiences only a few students receive training in the art of conducting and communicating research findings, while a well-structured CURES affords the opportunity for a large number of students to participate in real-world research training. Each course-based research endeavor consists of five components: research activities, discovery, relevance, collaboration, and iteration. The five components of CURES distinguish it from other active learning approaches and represent a major improvement from recipe-structured laboratories that dominate many academic environments. Experimental findings from empirical investigations indicate that CURES produce an upsurge in retention, student engagement, student satisfaction, and comprehension of science process skills.

KEYWORDS: CURES, broadening participation, STEM, undergraduate education.

INTRODUCTION:

Course-based undergraduate research experiences (CURES) represent a novel pedagogical approach designed to engage students in meaningful authentic hypothesis-driven experiences that mimic academic and industrial research environments. CURES have been implemented at many institutions and have been designed for many disciplines (Ayella & Beck, 2018; Lloyd, Shanks, & Lopatto, 2019; Marshall, 2019; Reeves, Warner, Ludlow, & O'Connor, 2018; Wooten, Coble, Puckett, & Rector, 2018). CURES are a student-centered instructional method that can be formulated for any STEM discipline. CURES provide a feasible plan to involve a large number of students in the research process. This is accomplished because the research endeavor takes place at the classroom level. Each student enrolled in the course participates in the CURES-based research project under the direction of a faculty member or faculty team. CURES provide a meaningful opportunity to explore the scientific method, lab safety, scientific communication, and research ethics. CURES engage students in real-world scientific investigations that have the capacity to alter conventional scientific thinking or lead to transformative changes in STEM fields. Conceivably, CURES can be established at the middle school level, high school level, or graduate level, however, this article focuses on the implementation of CURES in STEM at the undergraduate level. In terms of research projects, research projects can be based on an individual faculty member's research agenda or based on the research agendas of multiple faculty members. Further, projects can involve individual courses or span multiple courses and undergraduate classifications.

A CURE involving chemical biology, biochemistry, and neurobiology demonstrated that students reported an increase in experimental design skills, attitudes, efficacy, interest in STEM, and a more comprehensive understanding of the scientific process (Kowalski, Hoops, & Johnson, 2016). In addition to increases in student outcomes, Kowalski, Hoops, and Johnson (2016) also reported that faculty mentors who participated in the CURE observed increases in research productivity. Indorf, Weremijewicz, Janos, and Gaines (2019) implemented a biology-based CURES for undergraduates and documented student increases in research skills and self-efficacy. Their data also demonstrated that students who participated in the CURE graduated faster than students who did not complete CURE laboratories. Another research study on CURES showed that CURE participants demonstrated better content knowledge, better attitudes toward science, and enhanced motivation when compared to non-CURE participants (Olimpo, Fisher, & DeChenne-Peters, 2016).

CURES Elements:

While CURES is steadily gaining momentum in the literature and Internet (CUREnet - https://serc.carleton.edu/curenet/index.html), the pedagogical framework has not yet reached the status of a theoretical framework. The five components of all CURES are research activities, discovery, relevance, collaboration, and iteration (Auchincloss et al., 2014). The aforementioned CURES components delineate other active learning approaches such as problem-based learning (Ceker & Ozdamli, 2016) and inquiry-based learning (Lonergan, Cumming, & O'Neill, 2019). The current article will define the five components of a CURE and explore implications of each component for STEM faculty and undergraduate administrators.

Research Activities:

As suggested earlier, most faculty will choose to engage in research projects that are directly related to their research agenda or are an amalgam of research investigations from several faculty members. The research project selected directly affects the discovery and relevance components and therefore should be carefully considered. The research projects should be manageable for college students and consistent with departmental infrastructure and funding. For projects that involve multiple years, consider increasing the level of difficulty each year. Creating a research flowchart that documents the overall research question, working hypothesis, and each experiment to be performed as well as how the results derived from each experiment will address the overall research question is essential. Flexible deadlines regarding completion of each stage of the research project is important. Before the research activities take place, it is imperative that faculty and students review and understand the research flowchart. A particularly beneficial CURES strategy is to divide the class into groups of 3-4 college students. The group approach reduces the stress of each group member and allows students to work together to complete various phases of the research project. Depending on the type of CURE design, student groups can either work on figures/tables for a joint publication with other groups in the class or work on a separate group-specific publication. CUREnet provides examples of CURE implementation models for faculty. The website presents projects from a wide array of disciplines in the biological and chemical sciences.

CURES are excellent for all classifications but especially for freshmen. CURES that extend over the course of a students' entire undergraduate career can have profound effects on workforce pursuits. In order to effectively train students on how the research process is conducted it is important that prior to experimentation that students learn how to generate a research question and a related hypothesis. Scientific database (e.g., Pubmed) training should also be included in the research activities prior to the experimentation phase. Additionally, students will benefit from an understanding of the features of primary sources versus secondary sources as well as an understanding on when primary sources are preferred over secondary and vice versa. During the iteration phase, student scientists may be required to locate specific methodologically articles in order to consistently produce the desired results.-

The inclusion of laboratory safety training is also paramount before students engage in experimental protocols. A quick evaluation via traditional or online lab safety quiz will ensure student comprehension of safety procedures. A basic primer in data analytic procedures should follow each experiment to show students how to analyze the results to determine if the results are consistent or contradictory to the hypothesis. Discussions on canonical data presentation schemes must also be incorporated in the research activities stage to guide students on accepted methods to present experimentally-derived results to the scientific community.

Discovery:

Without question, one of the greatest joys of working in a laboratory is the feeling one gets when experimental investigations lead to novel results. CURES are far superior to “cookbook” labs in the area of discovery. In traditional laboratories,

particularly laboratories taught using lab manuals the final result is known and has been previously elucidated by many students around the world. While instructors can use lab manuals to help students perform specific procedures, the research findings of CURES are unknown prior to the commencement of experimental activities.

Student ownership is an important yet intractable student objective to achieve in STEM courses (Chan, Graham-Day, Ressa, Peters, & Konrad, 2014). Student ownership is a student perceived belief that the outcomes and products generated in an academic environment are the result of their own hard work, ingenuity, comprehension, and self-efficacy. Student ownership has been shown to improve student achievement, motivation, engagement, and self-efficacy (Brookhart, Moss, & Long, 2009; Corwin et al., 2018). Ownership outcomes are typically aligned with graduate school and professional school objectives and are associated with academic and industrial environments. Thus, increasing student ownership opportunities at the undergraduate level will allow STEM faculty to better mirror post-graduate environments. Studies derived from a one-semester CURE in a physical chemistry course reported increased student ownership of laboratory activities (Williams & Reddish, 2018).

Incorporating discovery in a traditional laboratory course is a simple proposition. A simple organism substitution, control addition, modification of clinical process, novel experiment, use of a mutant strain versus a wild-type may lead to new discoveries and the production of new knowledge. Allowing students to design their own experiments and generate their own hypothesis and research questions may also facilitate student ownership outcomes. In their recent study, Cooper, Blattman, Hendrix, and Brownell (2019) showed a link between discovery-based lab experiences and student project ownership. Using an immunology-focused CURE, they showed that students who engaged in a lab in which the results were not previously known, resulted in a cognitive and emotional ownership of their research project compared to a research group conducting studies in which the results had been deduced previously. Since, both groups of student participants were taught by the same instructor, differences in perceived student ownership can be attributed to treatment type.

Relevance:

CURES are different from other traditional laboratory exercises in that the data derived from student projects are of particular interest to the scientific community. Relevance also applies to results that have societal implications or results that can be applied to help humanity. Research activities that are focused on emerging pathogens or diseases (e.g., COVID-19) have the potential to be relevant. Also, research activities that address gaps in fundamental knowledge are typically considered relevant. In a CURE, the activity should be designed such that the results and methods are relevant to others. Project relevancy has the potential to enhance student motivation and engagement.

Collaboration:

Science, at its core, is a collaborative endeavor. Dividing students into work groups to accomplish specific research tasks will enhance collaboration. Alternatively, you can assign individual students to complete specific projects that address the overarching research question. Individual students will then compile their figures and tables to generate a complete research narrative or publication. Either strategy will promote the notion that collaborations are important and necessary in scientific research. The collaboration component found in CURE designs mimic industry and academic laboratory groups and are critical during the data analysis and manuscript preparation stages.

Iteration:

It is often said that people learn more from their mistakes then their successes. Under the proper mentoring, students can build knowledge and understanding even when experimental results are not expected or erroneous. Adequate time must be incorporated to complete each stage of the project. Careful consideration must be taken to ensure that there is sufficient time for protocol iteration. In "cookbook" labs, due to their high probability of success, the expectation is that the experiment will work the first time. This is not the case for CURES in which discovery is a fundamental component. Iteration and discovery are probably the two most important characteristics of a CURE in terms of alignment with real-world laboratory experiences.

CURES Design:

The design of the CURE is a very important success factor and requires a considerable amount of time. Decisions regarding the development of the CURES should involve multiple institutional stakeholders. The author contends that CURE development should also involve external scientists, experts, and educators. The goal of the CURE is to mimic real-world graduate level and workforce environments so including the viewpoints of current and former practitioners in the design of the CURE is potentially invaluable and necessary. CURES should have defined goals, objectives, student expectations, experimental techniques, and multiple checkpoints that can be easily measured to determine compliance and to determine whether modifications are necessary.

There are advantages and disadvantages to CURES based on the work of a single research agenda or based on the work of multiple researchers (Kowalski et al., 2016). Moreover, there are advantages to designing individual CURE modules to be implemented within a single course or multiple courses or designing a CURE in which specific figures and tables will be generated over multiple semesters. From a practical perspective, a CURE that involves multiple faculty may alleviate potential time concerns regarding expert accessibility. Ultimately, the selection of the most impactful CURES design will depend on what works for your department or institution according to the data generated from an assessment of faculty expertise, funding, resources, and infrastructure.

CURES and Faculty Benefits:

Prominent research institutions excel in research productivity because employment contracts at research-intensive institutions are structured to accommodate the enormous time required to engage in relevant research studies. However, at community colleges and most minority-serving institutions the majority of the employment actions are spent teaching and advising students. Engaging in faculty-mentored research at these types of institutions is extremely difficult. A major benefit of CURES is that course-based research endeavors allow faculty the opportunity to conduct research during class. The utilization of class time to conduct research solves the faculty time restriction problem. Additional time devoted to research at teaching institutions may result in higher publication productivity, the generation of preliminary data, the acquisition of research funding, and procurement of new scientific equipment through successful grant proposals.

Broadening Participation in STEM:

It is estimated that the STEM workforce will produce a significant number of jobs in the next few years (Noonan, 2017). Further, it is generally believed that due to a lack of qualified STEM workers many of these jobs will go unfilled. Thus, over the last decade a serious push has been made to better prepare students at all educational levels to deal with the expected labor surplus and to sustain the United States' standing in the global economy. Moreover, the lack of diversity in the STEM workforce continues to be a major problem in the United States (Nilsson, 2017). A copious amount of federal broadening participation programs have been implemented over several decades to improve minority student preparation and thereby broaden participation in STEM education and careers. Broadening participation in the STEM pathway involves many factors including self-efficacy, career interest, student engagement, career training, effective mentoring, and is dependent on the retention of students in the STEM pipeline (Flowers, 2019).

Due to the enormous demands on time and lack of resources there is a perpetual deficit of available independent student research opportunities at virtually every institution of higher education. It is generally understood that less than 5% of available STEM students are able to engage in real-world research experiences with a faculty mentor. Additionally, what we observe is that minority students typically fail to meet selection criteria even at HBCUs (historically black colleges and universities) and other MSIs (minority-serving institutions) and do not have an opportunity to benefit from independent hypothesis-driven research experiences. This is most unfortunate because previous research studies suggest that African American student participation in scientifically relevant lab experiences improve retention in STEM education and interest in science and engineering careers (Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998).

While all STEM departments suffer from resource depletion issues and budget problems that affect the quality of academic programs, most MSIs have more severe and chronic problems regarding funding and research infrastructure. The financial issues that plague MSIs make CURES implementation an ideal choice for improving minority student opportunities to conduct research and obtain the reported student outcomes derived from inclusion in the scientific research process. CURES adoption will create opportunities for entire STEM departments from MSIs to be involved in undergraduate research experiences that are similar to research-intensive colleges. Adoption should result in increases in retention in STEM over time. Further, according to the literature, increased retention should improve graduation rates and fuel student motivation to continue through the STEM pathway (Banks & Dohy, 2019; Dagley, Georgiopoulos, Reece, & Young, 2016).

CONCLUSION:

CURES are broadly defined as a pedagogical approach designed to implement authentic hypothesis-driven research experiences into the fabric of academic courses. CURES seek to address the inherent deficiencies of traditional laboratory exercises by focusing on particular scientific questions in laboratory for which the result is not predetermined (Brownell & Kloser, 2015). CURES allow for more undergraduate involvement in the scientific research enterprise and have been suggested as a potential tool to broaden participation in STEM research and improve the trajectory of underrepresented students in the STEM pathway (Bangera & Brownell, 2014). Empirical investigations into the effects of CURES on student development is a rapidly growing body of educational research and has led to the development of quantitative assessment instruments to measure its impact (Corwin, Runyon, Robinson, & Dolan, 2015). CURES literature has reported many favorable student outcomes following the integration of real-world research experiences into undergraduate laboratory courses (Brownell, Kloser, Fukami, & Shavelson, 2012; Kortz & Van der Hoeven-Kraft, 2016; Shanle, Tsun, & Strahl, 2016). In terms of underrepresented students, early and continuous exposure to research experiences have been shown to contribute

to desired institutional objectives such as increased retention, higher graduation rates, and pursuit of careers in science and engineering.

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